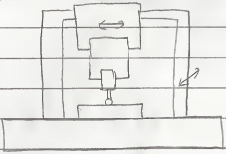
5 - Out of flatness

* Flatness error: It is the depature of the surface from a true flat plan
- Out of flatness: It is the min. distane between 2 plans containing all the irregularities of the tested surface

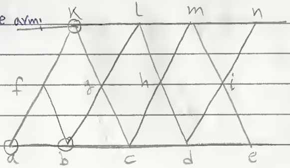
* Experimental procedure:
- The entire surface is divided into a series of imaginary straight lines form a grid and the variations in heights of points of intersections of lines are determined experimentally relative to some datum plane
- The experimental readings are then modified to become relative to the true mean plan

* Experimental techniques:

1 - Using CMM: For small size



2 - Using Rotitable arm:



Position
abc
bcd
cde
afK
cgK
fgh
ghi
bgL
KLm
Lmn

Position	Reading Z	1st p	midle q	last r	Height r = z+q-p	Point	value
abc	5	0	0	2	r=5+0+0	c	5
afK	-3	0	—	0	3+24	f	1.5

↑ — or 0

Date.

3 Using sensitive level

	22	23	24	25	
21					
16		17	18	19	20
11		12	13	14	15
6		7	8	9	10

1 2 3 4 5

x_i	y_i	Reading FWD	Reading BWD	Angle	Accumulated Degree	Accumulated mm

* Out of flatness calculations:

1- least square method:

$z_i = a x_i + b y_i$

$\bar{x} = \frac{\Sigma x_i}{n}, \quad \bar{y} = \frac{\Sigma y_i}{n}, \quad \bar{z} = \frac{\Sigma z_i}{n}$

$x_i' = x_i - \bar{x}, \quad y_i' = y_i - \bar{y}, \quad z_i' = z_i - \bar{z}$

$$a = \frac{\Sigma y'^2 \Sigma x' z' - \Sigma x' y' \Sigma y' z'}{\Sigma x'^2 \Sigma y'^2 - (\Sigma x' y')^2}$$

$$b = \frac{\Sigma x'^2 \Sigma y' z' - \Sigma x' y' \Sigma x' z'}{\Sigma x'^2 \Sigma y'^2 - (\Sigma x' y')^2}$$

Out of flatness $= z_i - \hat{z}_i$

E.g.

x_i	y_i	z_i	x_i'	y_i'	z_i'	$x'z'$	$y'z'$	x'^2	y'^2	...
$\bar{x}$	$\bar{y}$	$\bar{z}$								

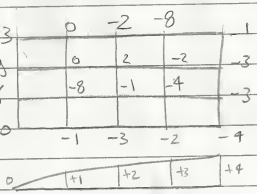
Subject. 36 Date.

2 _ Semi-analytical:

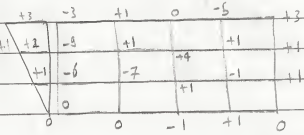
_ Rotate the points about lines, till they are symmetric about a line.

Example:

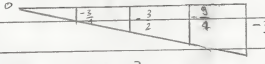
Rotate about (0, -3) line to make (y-4) line horizontal

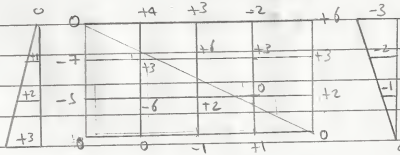


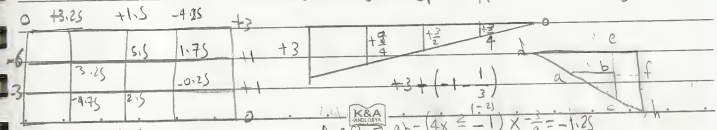
Rotate about (a, a) line to make (0, -y) line horizontal



Rotate about diagonal (0,0) to make the plane symmetric about a plan (up = down)







Δ abh $\Rightarrow$ $ab = \left(4 \times \frac{(-2)}{5} - 1\right) \times -\frac{5}{4} = -1.25$

Δ cde $\Rightarrow$ $bc = (3 \times \frac{-3}{4} - 1) \times -1 = -1.25$

Sum = 12 ≠ 0 ⇒ Subtract from each (c) ; $c = \frac{12}{20} = 0.6$

Point	Height (mm)
1	+2.4
2	+1.65
3	-0.1
4	+1.15
5	-0.6
6	-3.6
7	-5.35
8	1.9
9	-0.35
10	+0.9
11	-6.6
12	+2.65
13	+4.9
14	+1.15
15	+0.4
16	-0.6
17	+2.65
18	+0.9
19	-4.35
20	+2.4

Sum = 0